4 Effects of land use on soil rehabilitation – a paired plot approach

In this section, effects of rainforestation on soils are assessed in a false time series approach on adjacent plots. Each paired plot represents a chronosequence as all sites had been under grassland, fallow or annuals before. In the 1990s one part per site was reforested, while the reference plot was kept under the previous management[55]. After ten years of increased biomass production and litter circulation, effects of the trees on soil were looked at to find out, whether rainforestation could contribute to site rehabilitation as claimed by the project. For the soil samples, the approach was to use t-tests at an α-level of 0.05 for each pair and parameter. Apart from soil sampling, litter production and decomposition were quantified on one paired plot under rainforestation vs. *Gmelina arborea*.

4.1 Land use history

Information on rainforestation and adjacent reference land uses as shown in tab.8 was obtained from semi-structured interviews with the respective land owners or tenants in 2005, through observations on site and from KOLB (2003).

Table 8: Land use history of the research sites in Leyte

Site	Denomi-nation	Land use
Cienda	Ci-1 to -9	see chapter 5
	Ci-RF Ci-Grass	• Planted March – June 1996 (KOLB 2003) distance 2x2, then 2x1m, one species per line • *Pueraria* and grasses (60cm high) between *Cocos* (approx. 10x10m).
LSU	LSU-RF LSU-Ann LSU-Grass	• Rainforestation random-planted 1993-5 successively, after experimental plots and fallow dominated by grasses, *Lantana sp*. and bamboo. No external inputs. Intensive weeding during the first year. Approx. 50% mortality of fruit trees after 5 years. • Annuals: Abaca, sweet potato and tubers planted 2004 after fallow and, previously, annuals and banana. • Grassland: *Pueraria*, grasses and ferns, approx. 60cm high, *Cocos* approx. 10x10m.
Marcos	Mar-RF Mar-Grass Mar-Gme	• Rainforestation random-planted in Feb 1995 after years of *Imperata*, then fruit trees and Ipil-ipil, a tree legume. Mulch (rice hulls) is applied around the trees; no synthetic inputs. • Short grass (10cm) after annuals, burned • *Gmelina*: Age approx. as adjacent rainforestation plot. Pure *Gmelina*, undergrowth dominated by ferns 60-80cm high.
Pangasugan	Pang-RF Pang-Gras	• Rainforestation: Planted Nov 96-Jan 97 as 2x2m lines in slope direction after *Cocos* / *Imperata*; high mortality. • Short grass (<10cm) used as pasture
Maitum	Mai-RF Mai-Grass	• Planted 'early 90s'. Contains *Gmelina sp*., *Swietenia* sp., *Acacia sp*. and other exotics. Previously *Imperata*. 2x2m distance, urea application at planting. • Short grass (<10cm) with rock outcrops. Degraded, under communal use.

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55 This was due to property, not intentionally as an experimental lay-out.

Site	Denomi-nation	Land use
Patag	Pat-RF	• Planted 1994 as 2x2m – 2x3m lines in slope direction, each line corresponding to one species. Urea was applied at planting. Previously *Cocos* and pasture.
	Pat-Grass	• Cleared 2003 for a transmission line, this plot consists of grass (10cm) and small bushes. Previously *Cocos* and pasture.
	Pat-Gme	• *Gmelina* was planted 1993
Punta	Pun-RF	• Planted in the 'early 90s', maintained by LSU. Intensive weeding during the first year. Contains *Gmelina sp.*, Sw*ietenia* sp., *Acacia sp*. and other exotics. The plot was ploughed and urea applied before planting. Previous land use *Cocos* and banana in the sampled middle slope area.
	Pun-Grass	• Grassland after cocoa and annuals, all between *Cocos* (approx. 10x10m).

During the first years after planting of the rainforestation plots, dead trees were replaced by the project. Regular weeding was carried out by LSU personnel for some plots during the first year after planting. Apart from sporadic coconut harvest, only one site, Marcos, yielded noteworthy amount of fruits in 2005.

4.2 Soil samples

All soil analyses presented in section 4 refer to topsoil from 0-20cm depth. This layer was expected to most clearly reflect biological and litter-related processes influenced by the recent land use changes. Results obtained at Cienda in 2004 (see chapter 5) had provided an orientation on the spatial variability of parameters. In consequence, composite samples were collected to increase representativeness of the plots for the experiments in 2005. From all but two plots, eight composite samples consisting of three individual samples each were taken. Exceptions were Cienda (eight individual samples) and Punta (five composites containing 20 individual samples each). All samples were analysed for pH, C, N, BR, SIR and phosphatase. For available cations and P_I less samples were analysed due to limited resources.

4.2.1 Soil carbon, nitrogen and pH

Soil organic carbon and pH were analysed for a project status report by Asio and co-workers (CENIZA ET AL. 2004). Increases over time were found for both on the rainforestation plot at Cienda, but with considerable fluctuations of pH. At first sight, obvious differences in organic matter were observed between sites depending on rock, drainage and erosion as long-term factors. For the different land uses at each site, soil organic carbon, total nitrogen and C:N-ratio at the respective pH are shown in fig.44.
pH was a relatively sensitive parameter to indicate differences between land uses. Values at rainforestation plots were lower than those of the paired land uses in 7 of 10 cases. This goes conform with observations of KELLMAN (1970) along a successional chronosequence in Mindanao, finding that pH decreased during (secondary) succession, especially after initial burning. Elevated pH could be observed at the recently burned Marcos grassland plot. The same tendency was found for C and N contents.
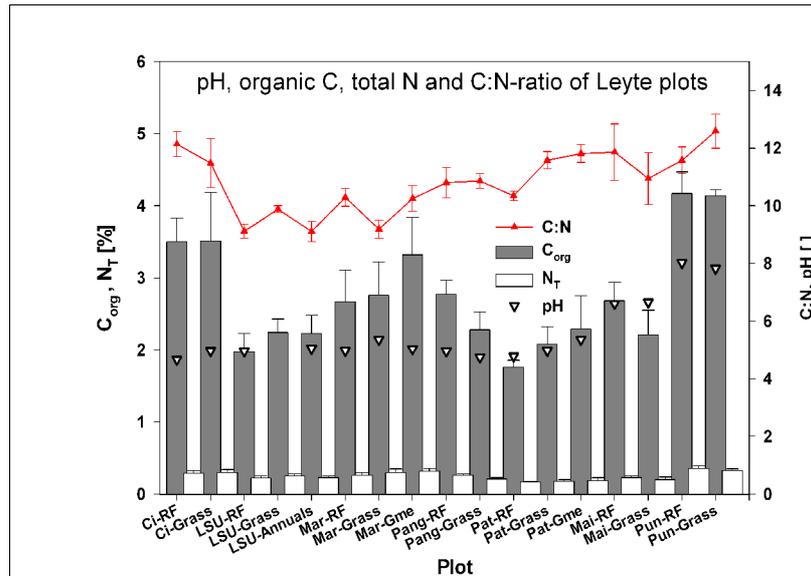
**Figure 44: Organic C, total N, C:N-ratio and pH for rainforestation and reference land use plots in Leyte**

With respect to C_{org} and N_T, tendencies between land uses were not obvious across sites. On the calcareous sites, both C and N were higher under rainforestation then under grassland. Where *Gmelina* was involved, C and N were elevated. Plots with the highest C and N contents were also the ones with the widest C:N-ratios. These are located at Cienda and Punta sites, where 'extreme' pH values prevail, and at the *Gmelina* plot at Marcos. Litter and humus accumulation were clearly visible at Punta, most probably due to the excessive drainage and high pH of the terrain. C:N-ratio turned out to be one of two most sensitive parameters for detecting significant (α = 0.05) differences between land uses (7 of 13 cases). In 3 of 4 significant cases between rainforestation and grassland, C:N-ratios were tighter under the first. At the two sites with adjacent rainforestation and *Gmelina*, one difference was significant, also with rainforestation showing the tighter C:N.

For C (LANGI in GEROLD ET AL. 2004) and N (KELLMAN 1970), a gradual increase has been reported following an initial drop after disturbance. V.NOORDWIJK ET AL. (1997) state, that belowground carbon stocks of well-managed pasture do not necessarily fall below those of tree-based systems. LEITE ET AL. (2004) simulated and measured decrease and recovery of C_{org} fractions after clear-cutting of Amazonian rainforest and organic inputs, while mineral fertiliser at least maintained the low levels.

4.2.2 Available Ca^{2+}, Mg^{2+}, K^+ and Na^+

Loss of basic cations after logging of forests in Sabah, Borneo, has been described by NYKVIST ET AL. (1994), who found particularly high leaching of potassium (>100kg/ha). A potential increase of basic cations in the topsoil as a consequence of tree-growing could be ascribed to transfer from the subsoil via tree roots and leaf litter or through leaching from leaves. Fig.45 shows concentrations of plant-available calcium, magnesium, potassium and sodium in the topsoils of the paired plots.

Calcium concentrations were dominated by parent material and highest at the calcareous Punta and Maitum sites. Lowest Ca^{2+} values were found at the acidic Cienda plots. Contents were rather site- than plot-specific. Significantly lower values (t-test, α = 0.05) attributable to land use were found for LSU-grassland compared to rainforestation and Marcos rainforestation compared to grassland. Considering also non-significant

differences, Ca was lower in rainforestation soils for 7 of 10 pairs.
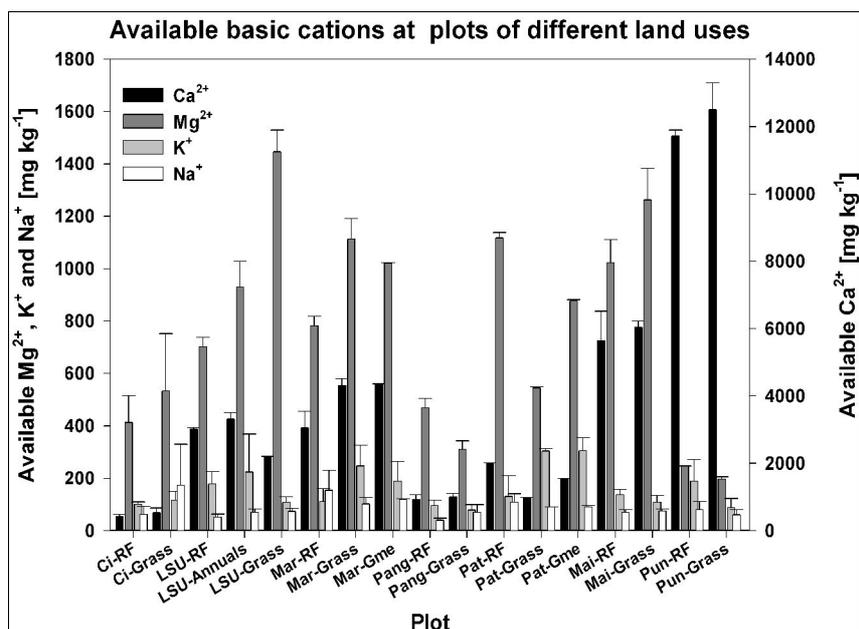
Figure 45: Available basic cations at rainforestation and reference plots in Leyte. Note separate scale for Calcium

Mg^{2+}, apart from C:N, proved to be the most sensitive of all parameters. Seven of ten paired land uses differed significantly with respect to available Mg. However, in 5 of 6 significant cases involving rainforestation, this system showed the lower Mg^{2+} values. The exceptionally low Mg^{2+} values at Punta site are supposedly due to replacement by Ca^{2+}. NYKVIST (1997) calculated for forested Acrisols in Sabah, that up to 50% of ecosystem Ca^{2+} can be bound in the vegetation. Although this ratio was only 3% for Mg^{2+}, amounts in tree-based systems (e.g. 0.6kg Mg^{2+} ton^{-1} tree biomass, same author) are considerably higher than for grassland, which may explain the lower contents in soil under rainforestation. Levels of potassium and sodium were statistically not distinguishable between plots and even non-significant differences showed no trend in favour of any particular land use.

4.2.3 Basal Respiration

Basal respiration describes the evolution of CO_2 during equilibrium microbial metabolism. Basal respiration (BR) as well as microbial biomass is strongly influenced by microclimate, with soil moisture ranging before temperature (WARDLE & PARKINSON 1990). Microclimate in turn is affected by canopy cover (through shading and litterfall), so that differences between open areas and closed-canopy systems could be expected. On a smaller scale, substrate quantity (SOM) and decomposability, reflected by C:N-ratios, are relevant for microbial parameters. Superior litter quality and decomposition of *Gmelina* leaves compared to those of indigenous trees (s.4.7.2) were likely to affect microbial activity reflected by BR. Basal respiration rates are shown in fig. 46 for the incubation period of 24 to 96h after conditioning as average per hour. Results display the same tendencies as during the first 24h (not shown), to the exception of Punta site, where BR was extraordinarily high at the beginning[56]. A long-term experiment (5.3.1.2) confirmed that BR rates usually take some time, even after conditioning to the lab environment, to reach an equilibrium.

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56 Probably due to carbonate set free from the calcareous soil material (SCHINNER ET AL. 1993)
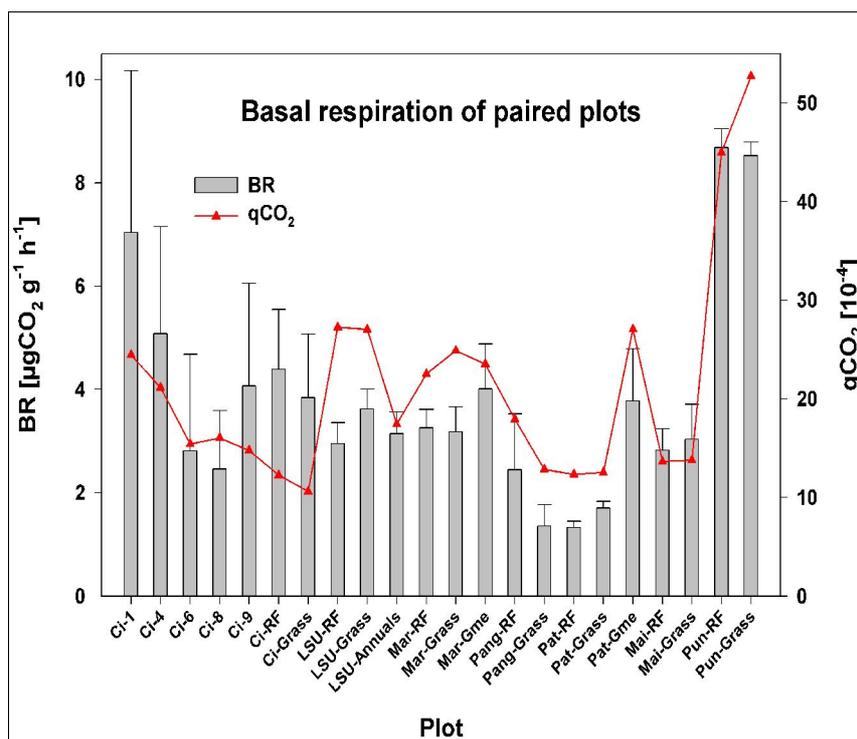
Figure 46: Basal respiration and qCO₂ after 4 days incubation for paired plots under different land uses

A clear site effect was the elevated BR at Punta, where rates surpassed those of all other sites by far. This may be attributed to the combination of high contents in organic matter (4.2) and of high biological activity (Daub 2002), but also to stress caused by high pH and excessive drainage[57]. An influence of stress is also suggested by elevated qCO_2, or basal respiration per unit microbial biomass, which is often interpreted as opposed to metabolic efficiency.

Elevated BR rates were also found under easily decomposable *Gmelina* litter. BR under *Gmelina* exceeded that of adjacent land uses in all 4 cases, for 3 of them significantly at $\alpha = 0.05$. For the Cienda subplots 1-9, the eroded subplot 8 under banana could be distinguished at $\alpha = 0.05$ from Ci-1, 4 and 9. For Cienda-RF and -grassland, high BR was associated to high microbial biomass, resulting in low qCO_2. Basically, qCO_2 followed BR to the exception of Cienda subplot 9, Ci-RF and Ci-grass; some peculiarities will be discussed under 4.2.4 in context with the microbial biomass C_{mic}.

Overall, most plots exceeded levels measured by Mao et al. (1992) under reforestation in tropical China (0.11-0.94µg CO_2 h⁻¹ g⁻¹), but remained below data reported by Menyailo et al. (2003) around 0.1 – 0.15gC kg⁻¹ d⁻¹ (equivalent to 15-25µgCO_2 g⁻¹ h⁻¹) for Amazonian soil samples incubated at 28°C and 60% WHC.

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[57] Samples were collected during dry season. This can be influential in spite of adjusted water contents of the samples.

4.2.4 Microbial carbon, Q10 and qCO₂

In contrast to other methods for determining microbial carbon (C_{mic}) in soils, substrate-induced respiration (SIR) is based on a flush of microbial respiration after addition of glucose and thus determines only C_{mic} of the actively metabolising biomass. This is of relevance, since most bacteria are in a dormant state at any given time, not participating in decomposition processes. While SIR focuses on young bacterial biomass, the standard fumigation- extraction method emphasises the fungal biomass (BRAKE ET AL. 1999).

Metabolic quotient or specific respiration qCO_2 is the proportion of CO_2-C evolved from basal respiration per unit microbial biomass C. The quotient characterises the energy necessary to maintain a certain population biomass (ANDERSON & DOMSCH 1986). High qCO_2 values are interpreted as low metabolic efficiency. This may be due to stress, caused e.g. by drought or substrate quality and land use (WARDLE ET AL. 1999) or soil depth (MAO ET AL. 1992). qCO_2 has been interpreted as an indicator of the successional maturity of a microbial community (INSAM & HASELWANDTER 1989; FLIESSBACH ET AL. in REES ET AL. 2001), following the theory, that community respiration decreases relatively to community growth from pioneer to maturity stage of an ecosystem (ODUM 1969). Another potential cause for comparatively higher qCO_2 mentioned by DILLY & MUNCH (1998) is a dominance of organisms specialised in easily decomposable substrates, e.g. of r-strategists over K-strategists or of bacteria over fungi. This argument seems to lead into the same direction as Odum's theory, if r-strategists are understood as pioneer species and K- or autochthonous species as typical for advanced stages of succession.

Theoretical digression: Incubation temperature and Q10: Incubation temperature is critical for microbial metabolism in general and for SIR in particular. During the first year, an air-conditioned room was not available and experiments had to be carried out at 32°C. In 2005, the set-up was 22°C, in line with standard procedures. In order to assess the influence of temperature on SIR, a simultaneous SIR experiment including both temperatures was undertaken as a pre-test in 2005 (fig.47) with samples across a broad range of soils and land uses. Following Arrhenius dynamics, an increase of factor two per 10K was expected for elevated temperatures. This Q10 factor has been assessed for qCO_2 of two European soils (Luvisol and Phaeozem), found to be 1.4 to 2.0 per 10K between 0°C and 45°C (ANDERSON & DOMSCH 1986). FANG ET AL. (2005) report values around
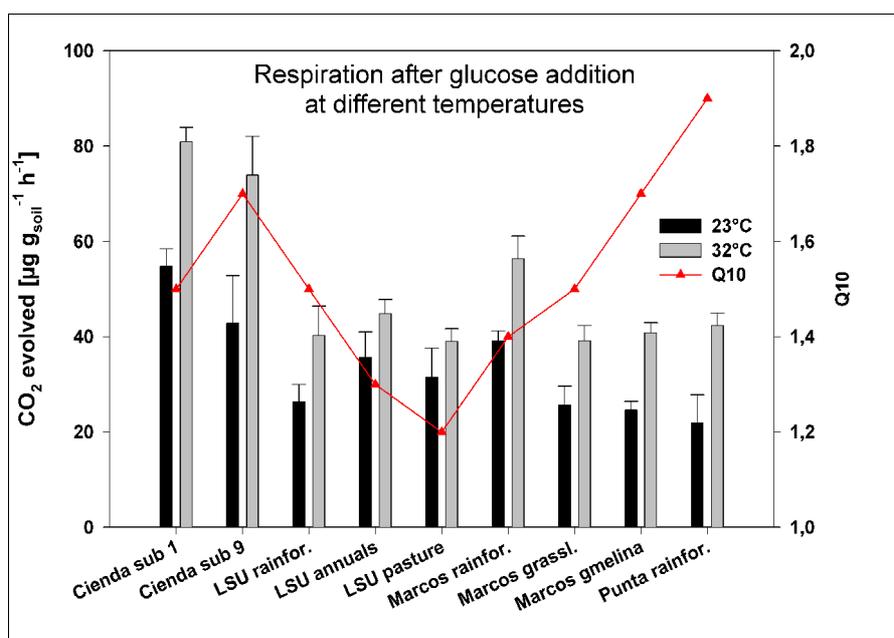
Figure 47: Assessment of Q10 for SIR experiments

2.1. In this study, not basal, but glucose-induced respiration as used for SIR was measured, and Q10 values between 22 and 32°C were found to be 1.2 to 1.9, depending on soil.


As stated, experiments in 2005 were carried out at 22°C. This is a prerequisite for the application of the conversion factor suggested by ANDERSON & DOMSCH (1978) to derive microbial biomass C_{mic} from respiration rates. Assuming a respiration coefficient of 1.0, a rate of $1mgCO_2$ 100g soil^{-1} h^{-1} corresponds to $20.6mgC_{mic}$ per 100g soil for temperate regions. Since a more specific conversion for tropical regions could not be found in literature, the original factor was used to express C_{mic} in fig.48 and later for C_{mic}/C_{org} ratios. Alternatively, qCO_2 was expressed as crude respiration rates, calculated as gCO_2-C evolved per kg soil and day. This is sufficient as long as samples are compared under equal conditions. However, rates were exactly in the range given by MENYAILO ET AL. (2003) for humid-tropical soils in Brazil[58]. C_{mic}-SIR quantified by MOREIRA (2004) in the Brazilian Amazon was at the lower end of the range determined in this study (150-200µg g^{-1} soil) with no significant differences between different land uses. In contrast to BR measurements, C_{mic} values at Punta site were in the normal range and even slightly below. For this reason an overestimation of C_{mic}-SIR in the calcareous Punta soil due to changed O_2 partial pressure (BECK ET AL. 1997) is not likely.

Concerning land uses, C_{mic}-SIR did not prove an appropriate distinguishing parameter at α = 0.05 level, however, as a tendency, rainforestation plots were relatively lower in C_{mic} for 7 of 10 pairs. The largest microbial population size was found at Cienda-RF and -grassland. Cienda -9 and LSU-Annuals had been disturbed in 2003 and 2004, so that the soil was not in equilibrium, and C_{mic} can be expected to fall back to normal levels during coming years. The peak is due to an exponential growth phase of microbial biomass after addition of substrate (here: mulch or crop residues) leading to higher production of CO_2 per biomass (ANDERSON & JOERGENSEN 1997). The same phenomenon was observed for the two *Gmelina* plots with easily decomposable litter: High qCO_2 was associated with intensive turnover of substrate.

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58 SIR carried out at 28°C
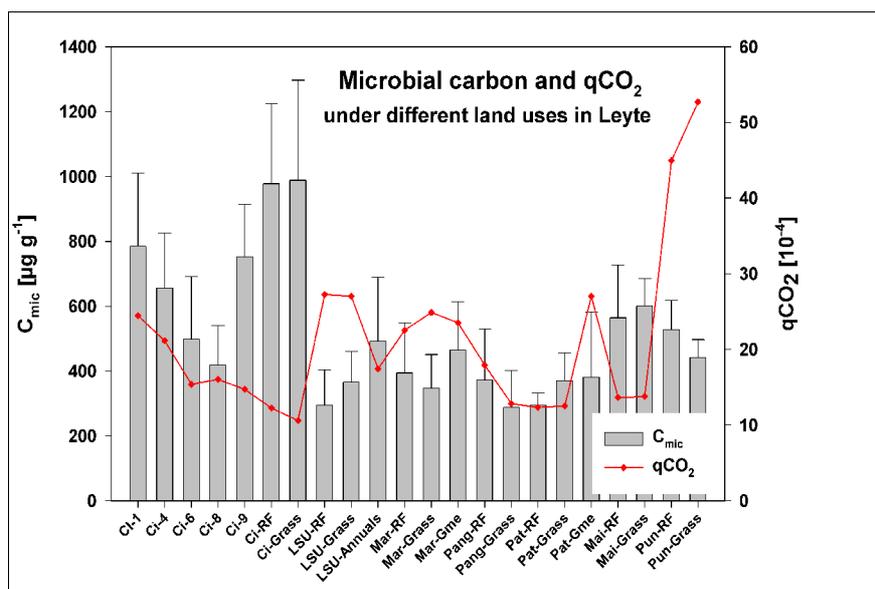
Figure 48: Substrate-induced respiration and qCO₂ under rainforestation and reference land uses in Leyte

Apart from intensive turnover, high qCO_2 can be the result of stress as in the case of the high pH value at Punta or the burned Marcos grassland. For the annuals plot at LSU as for the disturbed subplot Ci-9, the surprisingly low qCO_2 may be due to a build-up of microbial population about one year after disturbance through planting. qCO_2-rates were very similar to those presented by ANDERSON & DOMSCH (1986) in a laboratory experiment assessing effects of different temperatures on qCO_2.

As assumed before, BR in the temporarily dry and alkaline Punta soil was an expression of stress, which is corroborated by the relatively low microbial biomass and consequently high qCO_2. In contrast, low BR presented for Ci-8 and Ci-RF was associated with high microbial biomass and thus small qCO_2, pointing to unfavourable but stable conditions for microorganisms (erosion and low OM for Ci-8 and acidity for Ci-RF). Thus, for Cienda RF, the large glucose-responsive microbial population is well adapted and efficient, meaning that maintenance requirements are low. Following this logic of short-term adaptation, temporal drought would have been the main stressor at Punta rather than pH.

Considering the more temperate climate (21°N, 23°C, 1600mm annual rainfall), results obtained by MAO ET AL. (1992) in China were in comparable magnitudes to those from Leyte: C_{mic}-SIR between 20 and 350µg C_{mic} g^{-1} and qCO_2 0.8 to 1.8µgCO_2-C g^{-1} C_{mic} h^{-1}.

The microbial portion of organic carbon, expressed as quotient C_{mic}/C_{org}, describes relative availability of substrate for soil microorganisms (ANDERSON & DOMSCH 1986) and can give an impression of amounts of organic inputs into a system and thus of management (ANDERSON & JOERGENSEN 1997).

In this study, C_{mic}/C_{org} turned out to be rather site- than land use-specific with exception to Maitum and LSU grassland as well as Patag rainforestation, which were higher than their alternative land uses (in Maitum significantly at α = 0.05). For acidic Amazonian soils, MOREIRA & MALAVOLTA (2004) found, that C_{mic}/C_{org} did not even differ substantially between primary forest and fruit tree plantations (around 2%). In acidic Amazonian soils analysed by FEIGL ET AL. (1995), microbial carbon amounted to 3-4% of C_{org} and in humid subtropical China ratios from 0.48 to 2.31% were found in different (agro-) forestry systems (YAN ET AL. 2003). In this study, C_{mic} ranged over a wider scale, from 0.67 to 4.1% of C_{org}.
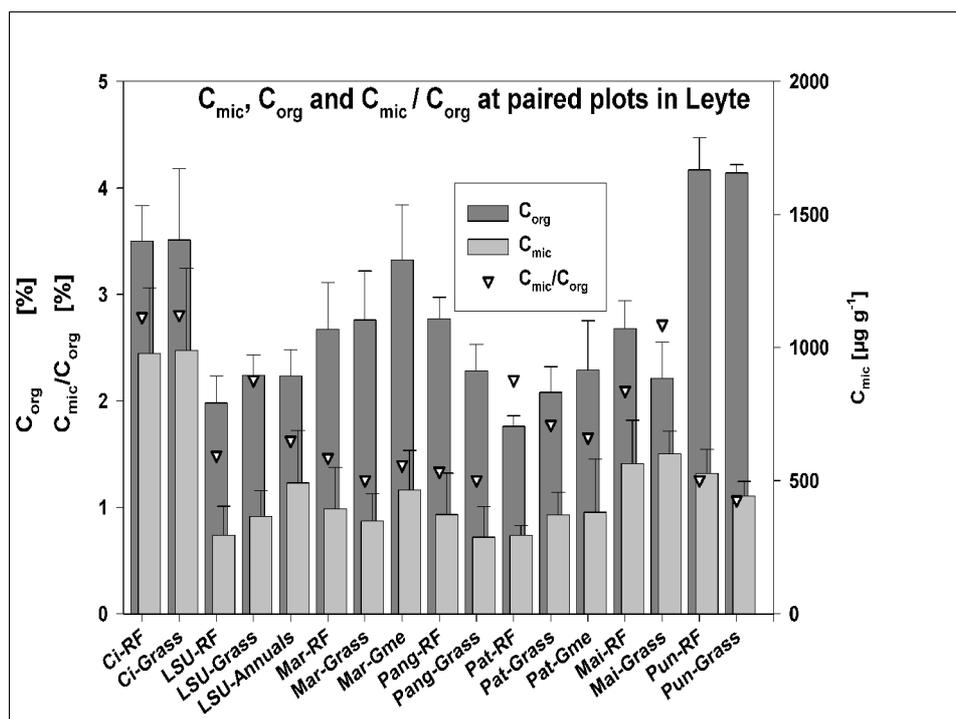
Figure 49: C_{mic}, C_{org} and the quotient C_{mic} / C_{org} for the paired plots in Leyte

4.2.5 Available P_I and phosphatase activity

Enzyme activities in soils have been interpreted as indicators for land-use, organic and microbial carbon and even 'sustainability' of a given land-use system. Enzymes react even more quickly to management changes than microbial biomass (DODOR & TABATABAI 2003). Phosphatases are secreted by plant roots and soil microorganisms. They transform P bound to organic macromolecules into plant-available inorganic forms. Acid and alkaline phosphatases are often analysed separately because they may originate from different sources (SCHINNER ET AL. 1993) and depend on soil conditions (GEORGE ET AL. 2002). For this study, phosphatases were determined at the respective given soil pH to account for different site conditions.

Phosphatase activity for the different plots in Leyte is shown in fig.50 in context with pH and $P_{Bray II}$ as influential parameters.

Soil moisture and temperature were controlled and calibration curves were very similar for all batches, thus photometer readings of different dates could be compared. In addition, composite samples were used in a separate experiment to confirm relative magnitudes of the different batches.
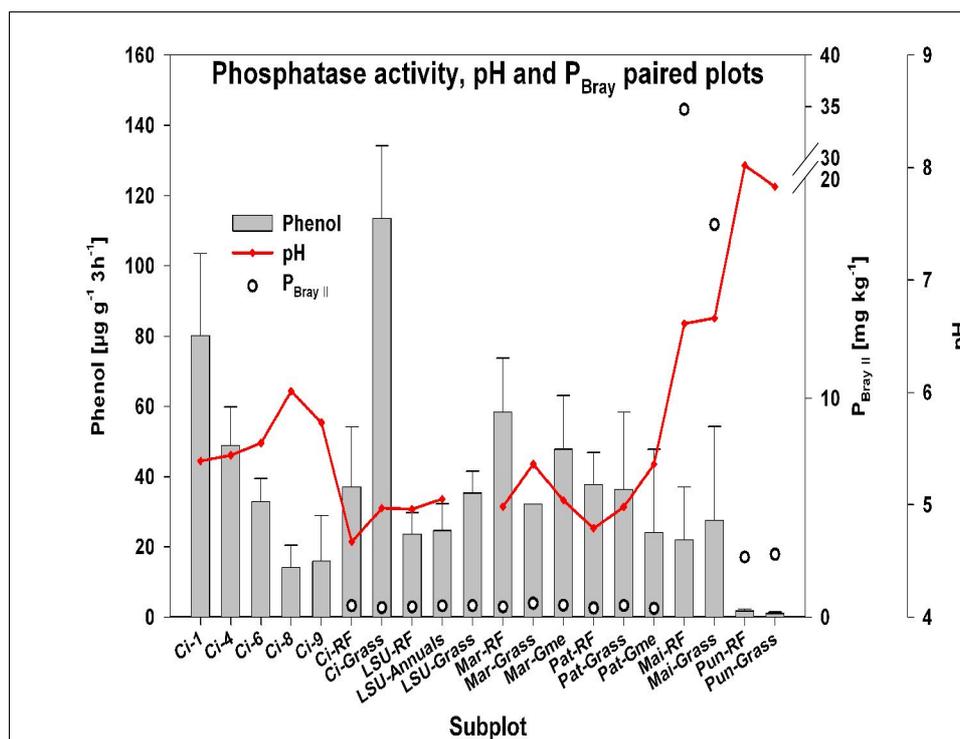
Figure 50: Phosphatase and P_Bray at paired plots

Results show especially for the Cienda subplots that phosphatase activity was inversely related to pH. This seemed to be the most influential factor as found by correlation analysis.

Increasing phosphatase activity with duration of the fallow period – as found by DENICH & KANASHIRO (1998) for acid phosphatase – can be observed for the Cienda subplots 1 - 9, if decreasing relative PAR is associated with fallowing (closing canopy). Vegetation as a source of phosphatases may have been of minor importance since roots had been sorted out before analyses. However, vegetation as a source of litter and thus P_{org}, the substrate for phosphatases, can be related to Cienda subplots 1-9, even if P-recycling through leaf litter may be limited to some extent by retranslocation before leaf fall (KHANNA 1998).

Phosphatase production is usually negatively correlated to P_I contents (YADAV & TARAFDAR 2001, DENICH & KANASHIRO 1998), which were expected to limit plant growth on all volcanic sites in Leyte (s. chapter 3; ASIO, personal communication; ZIKELI 1998). For Marcos rainforestation and *Gmelina*, however, levels of phosphatase exceeded those under grassland. This could indicate, that trees were not able to significantly increase P_I levels through nutrient pumping from the subsoil. If root phosphatases would have been involved, these would probably have had a higher share in the topsoil under grassland. This may have been the case for Cienda and LSU, where fallows were of relatively high biomass.

Decreasing contents of P_I with progress of succession have been reported by LEHMANN ET AL. (2001), but for the sites in Leyte, Bray II - P_I contents were too low in most cases to give distinguishable tendencies. Even values at Maitum would still classify as *low* according to the evaluation scheme by PAGEL ET AL. (1981). The grassland plot at Marcos was the only place where signs of burning during recent years could be observed in the field. Insofar increased pH and slightly higher P_{Bray} contents are typical (KELLMAN 1970).

4.3 Leaf litter production and decomposition under different tree systems

A paired plot of rainforestation on one side and *Gmelina* on the other was selected to assess litter cycling. To account for seasonal effects, litter traps and minicontainers were set up during the transition period from rainy into dry and again into rainy season 2006 (March 1st – June 15th).

4.3.1 Leaf litter production

With respect to litterfall, orders of magnitude on a dry matter basis were similar for both systems. Clear seasonal leaf-shedding was also observed in both. On the rainforestation plot, the peak of leaf shedding preceded that of *Gmelina*. Simultaneously to leaf fall, a period of flowering (and then abscission of flowers) could be observed in *Gmelina* (fig. 51). Due to the higher species diversity, fruits and flowers (F&F fraction) fell more uniformly on the rainforestation plot. Bark and branches (B&B fraction) were similar for both land uses with an increase towards the dry season.
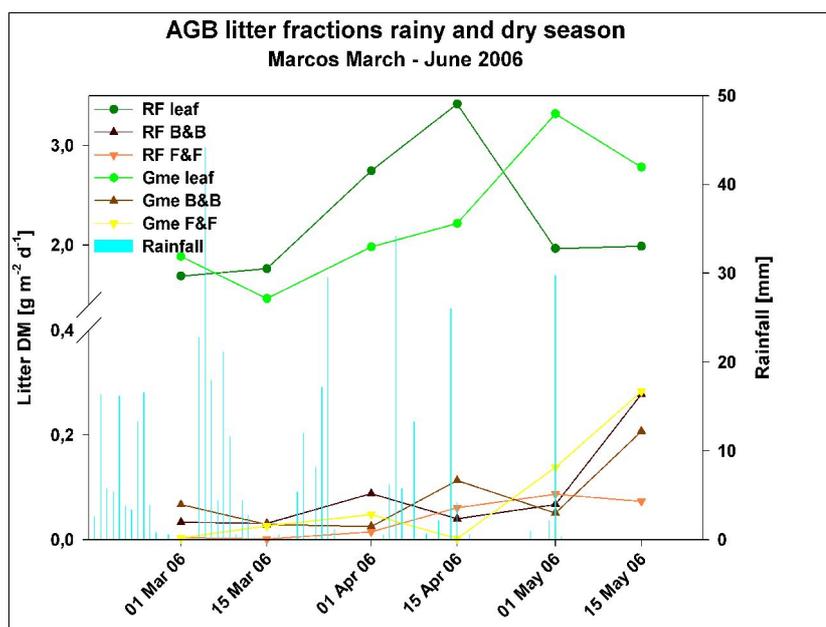

Figure 51: Time series of different litter fractions at Marcos rainforestation and Gmelina sp. plots. Daily amounts of rainfall

Generally, standard deviations of F&F as well as of B&B were high. At ten replicates per plot, coefficients of variation were between 150 and >200% for both fractions and systems. For leaves, CV were 40% for *Gmelina* and 51% for rainforestation, thus temporal patterns can be described best only on a leaf basis. An influence of the dry season can be deduced for *Gmelina*, but not as obviously for the rainforestation plot with its more diverse species composition.

4.3.2 Litter decomposition

Rates of litter decomposition influence nutrient cycling in tree-based systems, with rapid turnover providing limiting minerals like P to plants but also increasing the risk of leaching, especially for K and N (ISAAC & NAIR 2005). On the other hand, slow decomposition maintains physical characteristics of organic matter like pore volume and structure, which improve the soil water balance. Mini-container experiments for an assessment of litter decomposition were installed on both plots during three different short periods with decreasing amounts of rainfall (fig.52). For the first set-up (Feb 18th – Mar 8th), a leaf mixture based on *Ficus spp*. from Cienda was used as a neutral reference. The second and third experiment were carried out with leaf litter from the respective plots. Minicontainer capsules covered with 4mm mesh tissue allowed access for the mesofauna, while 0.1mm did not, so that both decomposer groups could be differentiated.
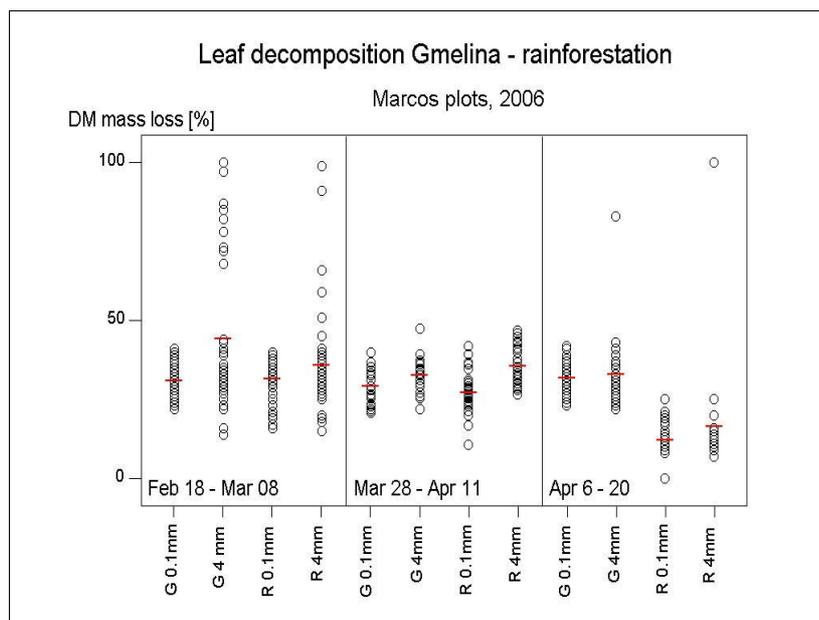
Figure 52: Decomposition of plot-specific leaf litter under different land uses in Marcos, 2006. R = rainforestation, G = Gmelina; 0.1 and 4mm are mesh widths of the minicontainer capsules

Dispersion and deviations were clearly higher for 4mm than for 0.1mm mesh width. A t-test between 0.1 and 4mm meshs showed, that for the period from Mar 28th to April 11th, decomposition in *Gmelina* and Rainforestation did not differ significantly (α=0.05), but from April 6th to 20th, *Gmelina* was decomposed to a significantly higher degree than rainforestation litter (α=0.01). Decomposition for rainforestation was clearly lower during the latter period (for both mesh widths, t-test P = 0.0000), while *Gmelina* maintained the same level or even increased slightly (P = 0.031). This coincided with scarce rainfall during both periods (60 and 58mm) and the observation that soil moisture decreased more in the rainforestation plot, which suggests inhibited decomposition caused by drought. ISAAC & NAIR (2005) explained increased leaf decomposition during the rainy season in Kerala, India, with higher microbial activity and substrate quality. BECK & GASPAROTTO (2000) underlined the importance of microclimate on decomposition in context with different land uses in Amazonia. Leaf analyses of trees for WaNuLCAS tree parametrisation (chapter 6) show, that litter quality probably played an important role for the faster decomposition of *Gmelina* (table 9). Tighter C:N and C:P ratios and lower percentages of polyphenolics can also be observed for the pioneer *S. palosapis* relative to the other indigenous trees. Polyphenolics such as tannins can hamper and have stronger effects on decomposition than C:N-ratios (ISAAC & NAIR 2005).

Table 9: C:N- and C:P-ratios and total extractable polyphenolics for leaves of Gmelina arborea and native trees

Species	Leaf C:N - ratio	Leaf C:P - ratio	Polyphenolics [% TEP[59]]
Gmelina arborea	12.3	188.8	1.56
Dipterocarpus validus	20.5	330.4	6.65
Shorea contorta	24.5	508.0	9.75
Shorea palosapis	20.0	266.0	6.33
Toona calantas	25.9	377.4	9.24

Faster decomposition of *Gmelina arborea* relative to *Dipterocarpus validus was also found by* ARAGON (2004) and BATISTEL (2004), who compared leaf decomposition of *Swietenia sp.*, *Tectona sp*. and *Gmelina arborea* to that of several indigenous trees.

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59 Total Extractable Polyphenolics

4.4 Synopsis

Rainforestation has been massively promoted in Leyte during the last decade. Discussions have often intended to prove the superiority of the rainforestation system, especially over the DENR approach that includes pure stands of exotic trees. Apart from general ecological questions[60], an important issue has often been overlooked or ignored: Rainforestation is a flexible concept that requires adaptation to each farmer's reality. Consequently there are as many systems as rainforestation farms. In practice, indigenous and exotic plants were often freely mixed, species diversity was not always high, understorey fruit trees often died and were not always indigenous species[61] and there was no uniform planting scheme or distance at all. This made it difficult to compare 'rainforestation' to other land uses, which were not always as pure as the *Gmelina* stand in Marcos. Especially the available grassland areas were not uniform, including *Imperata*- and *Pueraria*-dominated areas as well as pasture.

Given these restrictions, some interesting tendencies appeared across most sites with regards to differences between land uses and correlations of parameters: Summarising the t-tests, pH under rainforestation was mostly below that of any reference use (7 of 10 cases, four of them significant). The same was true for contents of Mg (six of ten cases, 5 of them significant). Ca was lower in rainforestation in 7 of 10 cases, but only once significantly. For P, contents were determined from one composite sample, so that no t-test was performed; contents under rainforestation were lower in 7 of 10 comparisons.

C, N, BR and C_{mic} were also each below the reference values in 7 of 10 cases each, but with only one significant case for C_{mic}, 2 for BR and N_T and 3 for C_{org}. This is opposed to the decline in total microbial biomass (fumigation-extraction method) after conversion of forest into agricultural areas observed by WALDROP ET AL. (2000) in Tahiti. C and N were lower than the reference plots in all rainforestation plots of low pH (volcanic rock) and higher at Punta and Maitum. The quotient C_{mic} / C_{org} was significantly different in only one case (Maitum), where rainforestation was below the reference land use. With respect to differences, cases of the remaining pairs were balanced.

Two sites showed clear overall trends across parameters: In Marcos, growth conditions under rainforestation were less favourable for all measured parameters except qCO_2 (which was higher under *Gmelina*) when compared to *Gmelina*, and except C_{mic} and qCO_2 when compared to grassland. The same was true for a comparison of LSU rainforestation with the LSU annuals field with exception to C:N and phosphatase. This shows that recently disturbed plots can contain higher levels of available cations and P as well as higher pH, especially after burning (Marcos). Elevated qCO_2 would then point to a young and growing microbial population, that has not yet adapted to the new conditions and is still to become more efficient. The same applies to *Gmelina*, where litter quality and / or quantity surpassed that of the reference land uses: Turnover and thus qCO_2 were elevated. MAO ET AL. (1992) ascribe elevated qCO_2 under *Eucalyptus sp.* compared to mixed monsoon forest to lower microbial diversity and thus reduced efficiency under pure stands.

Comparing *Gmelina* to rainforestation at Patag and Marcos, *Gmelina* was more favourable in both cases with respect to C, N, phosphatase (lower), K, BR and C_{mic}. Grassland showed higher BR and C_{mic}, P and Ca contents than rainforestation in 6 of 8 pairs. On the other hand, qCO_2 was also higher in these cases.

Looking at the potential of parameters to differentiate land uses, these belong to three

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60 e.g. how far can indigenous trees be replaced by exotic species, and to which extent can structural or functional diversity substitute species diversity (RUSSELL 2002)

61 Most are cultivars from Mindanao and at least Durian is exotic (LANGENBERGER pers. comm.)

categories of different time-scale. Firstly, enzymatic and microbial parameters indicating short-term effects of land use changes (DODOR & TABATABAI 2003; ANDERSON & DOMSCH 1989) as shown on the Cienda subplots for phosphatase or qCO_2 for the recently disturbed LSU-annuals plot. Secondly, pH as a medium term-indicator, and thirdly, available nutrients on a longer scale. Under this aspect it was surprising, that clear differences between land uses could already be observed with respect to available cations, especially Mg, within 10 years after reforestation.

With regard to relevance of mechanisms for soil development, it was of interest to look at relationships between the evaluated parameters across all sites and plots. Correlations between the most relevant parameters are shown in tab. 10, values for BR and qCO_2 - 24h being omitted.

Table 10: Correlations between analysed soil parameters across different sites and land uses in Leyte[62]. Significance at α = 0.05 is indicated by *, at α = 0.01 by **.

	pH	C	N	C : N	P-ase	P_{Bray}	Ca^{2+} av	Mg^{2+} av	K^+ av	Na^+ av	BR 72h	C_{mic}	QCO_2 72
pH	1	0,527**	0,395**	0,408**	-0,449**	-0.377	0,808**	0,609**	0.145	-0.014	0,597**	0.061	0,434**
C	0,527**	1	0,909**	0,476**	0.062	0,722*	-0,388*	-0,325*	-0.107	0,487**	0,796**	0,449**	0,348**
N	0,395**	0,909**	1	0.077	0.081	0,758*	-0,341*	-0.208	0.125	0,361*	0,699**	0,309**	0,367**
C : N	0,408**	0,476**	0.077	1	0.001	0.255	-0.140	-0.289	-0,416**	0.288	0,390**	0,404**	0.043
P-ase	-0,449**	0.062	0.081	0.001	1	-0.244	-0,520**	-0.220	-0.168	0.325	-0.067	0,410**	-0,308**
P_{Bray}	-0.377	0,722*	0,758*	0.255	-0.244	1	0,951**	-0.445	-0.010	-0.118	0.377	0.378	-0.039
Ca^{2+} av	0,808**	-0,388*	-0,341*	-0.140	-0,520**	0,951**	1	0.247	0.144	-0.069	-0.188	-0,394*	0.079
Mg^{2+} av	0,609**	-0,325*	-0.208	-0.289	-0.220	-0.445	0.247	1	0.224	0.134	0.101	-0,414*	0.337
K^+ av	0.145	-0.107	0.125	-0,416**	-0.168	-0.010	0.144	0.224	1	0.109	-0.037	-0.271	0.265
Na^+ av	-0.014	0,487**	0,361*	0.288	0.325	-0.118	-0.069	0.134	0.109	1	0,467**	0.332	-0.144
BR 72h	0,597**	0,796**	0,699**	0,390**	-0.067	0.377	-0.188	0.101	-0.037	0,467**	1	0,276**	0,637**
C_{mic}	0.061	0,449**	0,309**	0,404**	0,410**	0.378	-0,394*	-0,414*	-0.271	0.332	0,276**	1	-0,444**
QCO_2 72	0,434**	0,348**	0,367**	0.043	-0,308**	-0.039	0.079	0.337	0.265	-0.144	0,637**	-0,444**	1
C_{mic}/C_{org}	-0.090	-0.104	-0.210*	0.183	0.325**	-0.298	-0.104	-0.197	-0.287	0.039	-0.201*	-0.789**	-0.739**

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[62] BR and qCO_2 after 24h incubation are not shown, because they tended to be less balanced than those after 72 hours. In the case of qCO_2 - 24h, correlations with pH (0.657**), C (0.591**), N (0.473**) and C:N (0.391**) were more pronounced than those for qCO_2 72h.

Strong correlations can point to dependence of one parameter on a limiting (for positive correlations) or restricting (for negative correlations) factor. pH and C_{org} were the most influential among all measured parameters. However, both were not too strongly interconnected across all plots as humus accumulation was typical for both ends of the pH scale. Under strongly acidic conditions free Al^{3+} can attenuate OM decomposition. At the calcareous sites, humus accumulation can be attributed to metabolic optima of most soil bacteria at slightly acidic conditions. For both extremes, characteristic fixation of P to minerals can be another reason for reduced microbial activity leading to humus accumulation. Overall, pH and P_{Bray} were inversely correlated. The strong positive correlation between Ca and P may point to apatite as a source of P_{Bray} dissolved by the HCl component of the extractant (PAGEL ET AL. 1982). This was supported by the fact, that for P_{Olsen} only traces were found in Punta soils[63].

Comparing correlations to those of KAISER ET AL. (1992), C_{mic} was significantly positively correlated to C_{org} and BR and so was C:N, for which KAISER ET AL. reported a negative correlation. For C_{mic} and N, correlations were positive in both studies, but weaker here, probably because N was not a limiting factor. A correlation of C_{mic} to pH as reported by ANDERSON & JOERGENSEN (1997) for temperate soils and in this study for BR to pH was not found; this is in line with studies by KAISER ET AL. (1992). In addition, the correlations were not very strong, probably due to the different soil types, including underlying factors of influence. Correlation between BR and pH was stronger, as shown before by JOERGENSEN & SCHEU (1999) and V.NOORDWIJK ET AL. (1997) and so were correlations between BR and C, N and C:N. Microbial activity (BR) and qCO_2[64] were both positively correlated to pH and consequently high at Punta and low at the acidic Cienda Nitisol. In this sense, positive correlations between C and N on one hand and qCO_2 are not interpreted as a relationship of stress, but as due to substrate supply. Under unfavourable conditions, metabolic efficiency and microbial population size would decrease – a highly significant and strong negative correlation $qCO_2 – C_{mic} / C_{org}$ was found. This was also observed by JOERGENSEN & CASTILLO (2001) for young volcanic soils in Nicaragua.

Microbial activity seemed to be more dependent on substrate quality than on P and cations. Both C_{mic} and BR were positively correlated to P, but not significantly. C_{mic} was negatively related to available Ca and Mg and positively correlated to phosphatase suggesting a common correlation of these parameters to an underlying effect.

The strong statistical weight of the Punta and Maitum sites can be noted from the clear correlation $P_l – Ca_{av}$. Sensitivity of the correlations to these two sites was strong for pH, C, phosphatase, Ca, Mg and all BR-related parameters including qCO_2. Correlations of N, K, Na and C_{mic}, however, did not change much, when the two sites were excluded from the calculation of the correlation table[65].

An important objective of the rainforestation project was rehabilitation of degraded lands. This would combine improvement of soil fertility, i.e. yield-related parameters, and soil quality as related to ecological functions of soils (FILIP 2002).

ASIO (1996) identified soil colour, reduced OM contents and soil respiration, increased erodibility and available basic cations as indicators of degradation and tested the hypothesis, that land use change would not necessarily lead to soil degradation. A principal conclusion was, that degradation was owed to the effect of clear-cutting, but

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[63] values obtained by Bray II roughly double those by Olsen and quadruple such by Truog extraction – s. PAGEL ET AL. 1982

[64] Contrary to a negative correlation in soils of similar pH range found by YAN ET AL. 2003

[65] Both tables were compared counting cases per parameter, where a correlation coefficient differed >0.4 between the full matrix and the one that excluded Maitum and Punta data. For the pH-sensitive group of parameters r changed in ≥5 of 16 cases, for the less sensitive group in ≤3 cases.

could not be attributed to any particular form of 'secondary' land use (here: *Cocos + Pueraria*, *Cocos* + bush fallow, pasture, slash & burn).

Concerning soil functions for sloping lands in Leyte, soil physical parameters counteracting erodibility appear most relevant to reducing erosion and the risk of landslides. These include organic matter, pore volume and bulk density as determinants of water holding capacity. Any build-up of biomass, preferably a closed layer producing large quantities of mulch, would improve these soil properties. Under the soil water and structure aspect, a thick mat of creepers such as *Pueraria* (s. OM contents in Asio 1996 or at LSU, Cienda, section 4.2) can be of similar efficacy as a multi-storey system, but interception and transpiration would be lower and deep-rooting less intensive. Thickness of litter layers under rainforestation has been described in chapter 3 for each plot. For grassland at Marcos, Pangasugan, Patag, and Maitum, litter was virtually absent. Under this aspect rainforestation would be preferable to grassland because of higher litter inputs, and to *Gmelina* due to slower litter decomposition. The role of plant species diversity on microbial efficiency has been discussed with respect to qCO_2 and the influence of different species on soil was illustrated by canopy and leaf litter production. An open question regarding ecological functions is, to what extent small-scale variability of soils influences species diversity, e.g. during germination. Effects of slope position on the composition of plant communities have been described by Langenberger (2003) for Mt. Pangasugan in the hinterlands of LSU, and for Cienda, but at a smaller scale, studies have not been conducted.

It has been stated, that rehabilitation of soils through natural succession is rather independent of soil nutrients, even though with some confinement with respect to Mg (Harcombe 1980). Filip (2002) used BR and SIR measurements, among others, to draw conclusions on soil functions at different levels of contamination. However, as soon as yields and rentability are concerned, nutrients would be a limiting factor. With respect to soil fertility, chemical parameters are of great importance and this was a focus of the present study since fertility is crucial for any cash crop growing under trees. Soil quality and fertility can be opposed under certain perspectives. While for the ecological functions, a slow decomposition of organic matter increases structural stability, growing organisms may benefit from rapid turnover of OM and cycling of nutrients. Having started on grassland areas, the rainforestation plots represent an advanced successional stage on the way to a potential forest vegetation, in contrast to the arrested development on grassland plots. It is well-known that nutrient cycles in tropical forests are tight and a substantial share of ecosystem nutrients is tied up in vegetation as succession progresses towards forest (Nykvist 1997), leading to depletion of soils (Harcombe 1980)[66]. In addition, Kellman (1970) reports a slight decrease of pH and P_l under advancing secondary succession. Mg^{2+} is subject to leaching and uptake into plants is depressed by other cations such as Ca^{2+}, but also H^+ (Marschner 1993). As a consequence, soil acidification accompanying succession would reduce nutrient availability (see the strong positive correlations of Ca^{2+} and Mg^{2+} with pH in tab. 10). Interveinal chlorosis denoted on *L. domesticum* under canopy at Cienda may be a prove for this. The results presented in this chapter confirm the relevance of these mechanisms for Leyte. Asio, Jahn & Stahr (1999) found higher concentrations of basic cations on plots after a conversion of forest soils in

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[66] On a basis of roughly 300Mg biomass ha^{-1} and 0.3% Mg in average plant tissues (after Marschner 1993) and about 5cmol$_c$Mg kg^{-1} soil at PN1 this would lead to a ratio of 12 in soil/plant within the rootable depth. Availability and leaching of Mg are not considered in this estimate, nor is leaching from leaves into the soil. For P, 5kg P_{Bray} ha^{-1} in the soil would support roughly 1000kg P in plants. Plant available P, however, makes up for only a small part contained in the soil resource (total P in soils is 0.01-3.4%; Pagel et al. 1982), while magnitudes for Mg^{2+} are similar in plant and soil.

Leyte, but ascribed this to enhanced weathering, presence of ash and a rejuvenation effect of soil erosion.

While nutrients are accumulated in the system as a whole, supply in the soil may decrease. While shifting cultivation makes destructive use of the minerals stored in the fallow biomass, simultaneous agroforestry systems must necessarily aim at increasing soil fertility of the developing system, including tree and crop components. For any shade-tolerant plant grown under canopy it is of vital importance that additional minerals provided by the nutrient pump compensate for the competitive effect of the tree component.

The bias between conservation and economic feasibility may be one reason for the lacking adoption of the system among target groups[67]. Rainforestation has not yet transgressed from a conservation concept to an economically viable alternative for farmers. Similar observations have been made by CRASWELL ET AL. (1997), who state, that labour is a *major constraint to the adoption of complex agroforestry systems* in Asia, as long as *external incentives* are not provided. The important role of early-yielding cash crops for the profitability of agroforestry systems has been discussed earlier. From this perspective, growth of the early-yielding species *Musa textilis* under varying vegetation and environmental conditions will be evaluated in chapter 5.

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[67] More than ten years after starting the project, 28 plots exist, integrating an area of approximately 10ha. The free distribution of seedlings and assumption of weeding through the project have not led to broader acceptance.